Verifying Forecasts of Maximum Mixing Height for Greensboro, NC

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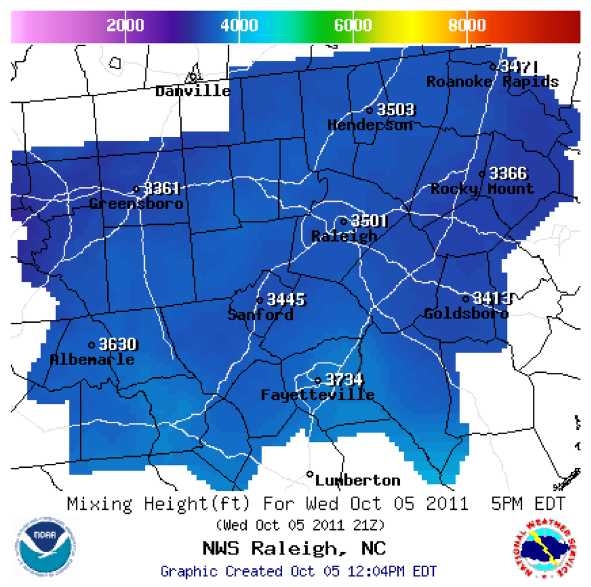
Introduction

The mixing height is defined as the height of the layer adjacent to the ground over which pollutants or any constituents emitted within this layer or entrained into it become vertically dispersed by convection or mechanical turbulence (P. Seibert et al. 2000). The National Weather Service (NWS) regularly produces forecasts of the mixing height to help users assess dispersion and anticipate air quality issues. Mixing height forecasts are provided to fire weather users through pre-suppression and gridded forecasts which are issued at least twice a day, and through spot forecasts which are issued as requested. Forecasts of mixing heights are also used to provide support for hazardous materials incidents.

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FIRE WEATHER PLANNING FORECAST FOR CENTRAL NORTH CAROLINA
NATIONAL WEATHER SERVICE RALEIGH NC
600 AM EDT WED OCT 5 2011

NCZ022-052115-
GUILFORD-
INCLUDING THE CITIES OF...GREENSBORO...HIGH POINT
600 AM EDT WED OCT 5 2011

                      TODAY       TONIGHT     THU

CLOUD COVER           MCLEAR      MCLEAR      MCLEAR
PRECIP TYPE           NONE        NONE        NONE
CHANCE PRECIP (%)     0           0           0
MAX/MIN TEMP          78          50          74
MIN/MAX RH %          32          84          40
AM WIND (MPH)         LGT/VAR                 NE  5
PM WIND (MPH)         LGT/VAR     LGT/VAR     NE  6
PRECIP AMOUNT         0.00        0.00        0.00
MIXING HGT(FT-AGL)    3400                    4300
TRANSPORT WND (MPH)   N  2                    E  9
VENT RATE (FT-MPH)    6800                    38700
DISPERSION                        VERY POOR
LAL                   1           1           1
HAINES INDEX          5           5           4
ADI EARLY             3 VERY POOR 3 VERY POOR 5 VERY POOR
ADI LATE              20 GEN POOR 2 VERY POOR 33 FAIR
MAX LVORI EARLY       6           3           5
MAX LVORI LATE        2           4           1

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Problem

The accuracy of mixing height forecasts is becoming more important to fire weather users and regulatory agencies given the growing public sensitivity to air quality issues. Despite the need, NWS mixing height forecasts are rarely verified, since the mixing height is not observed directly, and must be estimated or parameterized from vertical profile measurements.

Methods to Estimate the Maximum Mixing Height

There are several methods to determine the maximum mixing height, but they vary considerably, are subject to their own limitations, and are dependent on the availability and resolution of vertical profile data.

Holzworth Method

The Holzworth method (Holzworth,1967) calculates the maximum mixing layer depth based on the afternoon surface temperature and the temperature sounding. This method lifts the surface parcel up the dry adiabat from the expected maximum temperature to its intersection with the temperature profile. The mixing height is taken as the equilibrium level of an air parcel with this temperature. It is dependent on the surface temperature and often the existence of a pronounced inversion at the top of the convective boundary layer.

Moisture Jump Method

The mixing height in the convective boundary layer can sometimes be identified as the height of a significant reduction in moisture, often accompanied by wind shear (Lyra et al., 1992). They described the mixing height for a convective profile as the height in which the mixing ratio decreased more than 0.01 g kg^1 m^1.

Potential Temperature Method

This method first noted by Heffter (1980) analyzes the potential temperature or virtual potential temperature profile for the existence of a critical elevated inversion, which is assumed to indicate the top of the mixing height. The mixing height is at the lower range of a layer containing a positive potential temperature lapse rate and a significant temperature increase. This method appears to be the most scientifically rigorous and was used in this study.

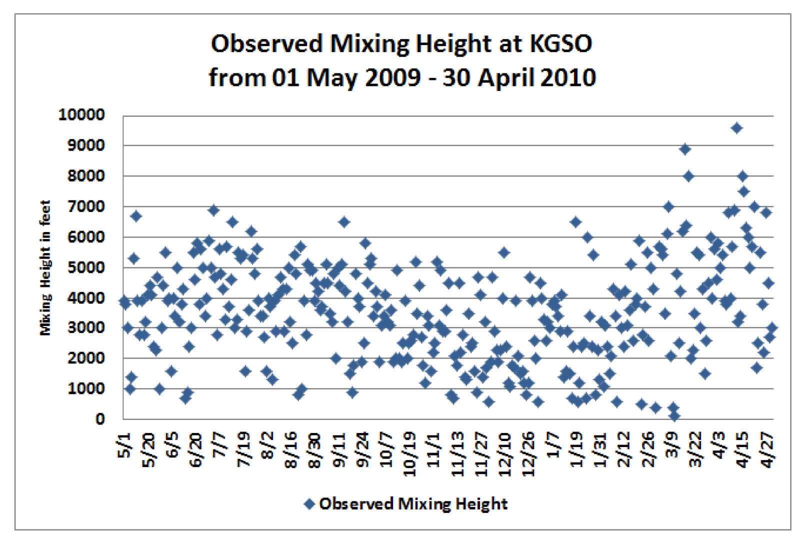
Methodology

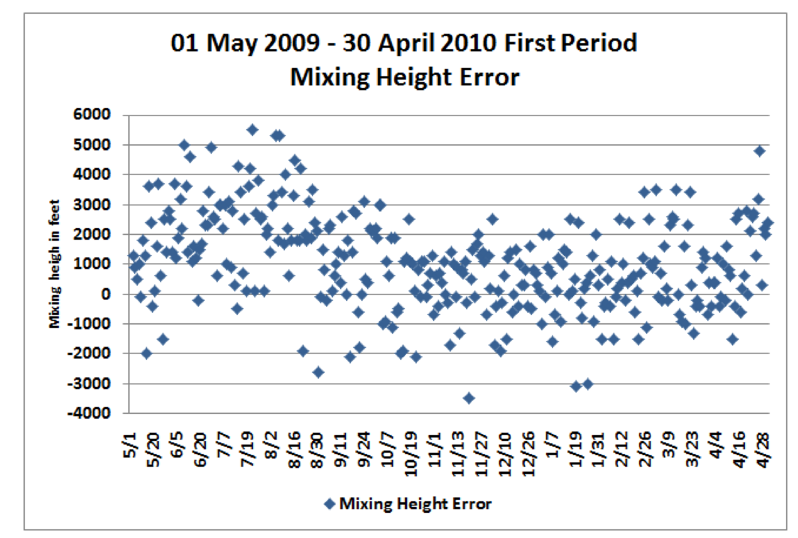
Forecasts of the daily maximum mixing height for Greensboro, North Carolina (KGSO) from 1 May 2009 through 30 April 2010 were subjectively verified. Vertical plots of virtual potential temperature, mixing ratio, Richardson number, and wind direction/speed were constructed from the 00 UTC and 12 UTC KGSO RAOB observations. The 00 UTC KGSO radiosonde observations were subjectively analyzed to determine the maximum mixing height during the previous convective day using the potential temperature method. Archived surface analyses, local radar imagery, and satellite imagery were used to identify synoptic or mesoscale features that would have made the 00 UTC radiosonde unrepresentative. A total of 38 days (~10% of all possible days) were removed from the data set because of missing observations or representativeness issues such as convection, frontal passages, or localized precipitation.

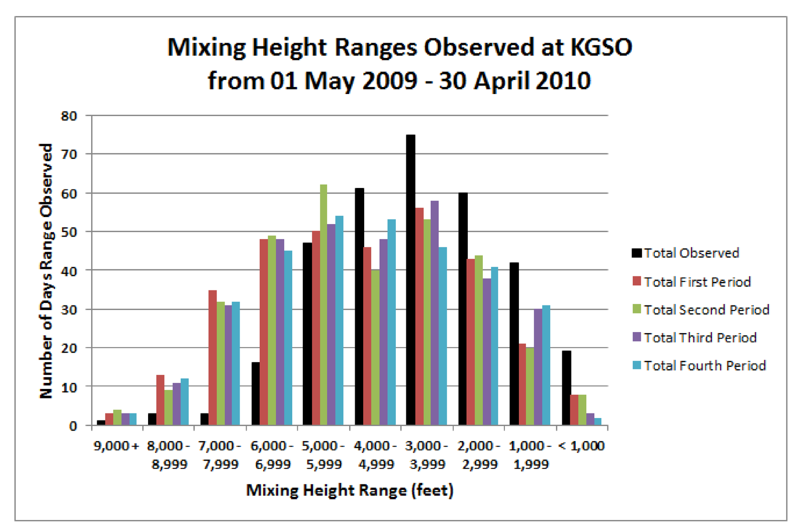
The maximum mixing height forecasts for the Guilford County, NC fire weather zone, which includes Greensboro (KGSO), were extracted from the Fire Weather pre-suppression Forecast (FWF) for each day of the study period. For each day, four forecasts are available, each from a different forecast cycle. A table was constructed containing the four forecasts available for a given day and the subjectively analyzed observed mixing height using the potential temperature method.

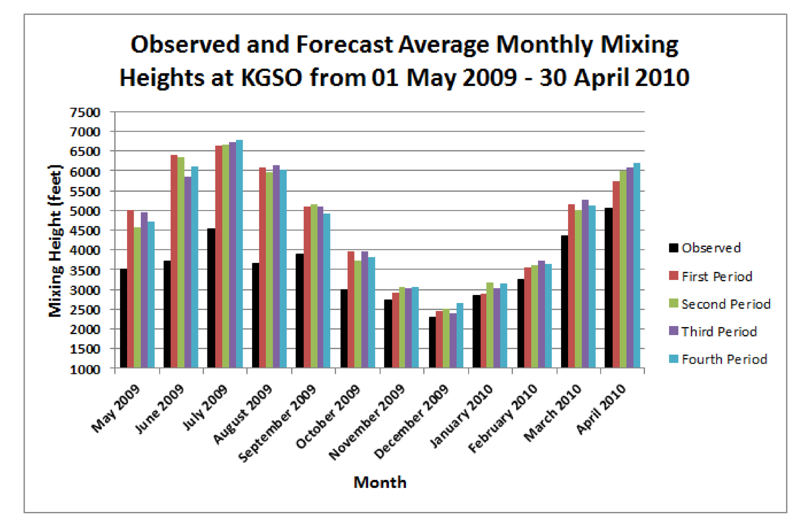
Results

• Observed mixing heights over the course of the year showed large day-to-day variability due to seasonal, synoptic, and mesoscale conditions.
• The average mixing height during the 327 days of available data was 3,566 feet, which is close to the average of 4,133 feet computed across 4 southeast U.S. sites by Garrett (1981).
• The average monthly observed mixing heights during this one year period were greatest in April and smallest in December.
• The greatest observed mixing height was 9,600 feet on April 12th, with three other days experiencing mixing heights between 8,000 and 8,900 feet.
• For first period forecasts, the average first period mixing height error during the 327 study days, was 1,487 feet with a mean absolute error of 58%.
• A total of 12 days had errors in excess of 4,000 feet, 42 days had errors of more than 3,000 feet, and 102 days (nearly a third) had errors of 2,000 feet or more.
• For first period forecasts, 239 days out of 327 (73.1%) verified too high, while 80 days (32.8%) were too low.
• A total of 196 days (60% of all days) had observed mixing heights between 2,000 and 4,999 feet with only 70 days (21% of all days) had observed mixing heights of 5,000 feet or more.
• Forecasts were most consistent with the observed during the winter and early spring.

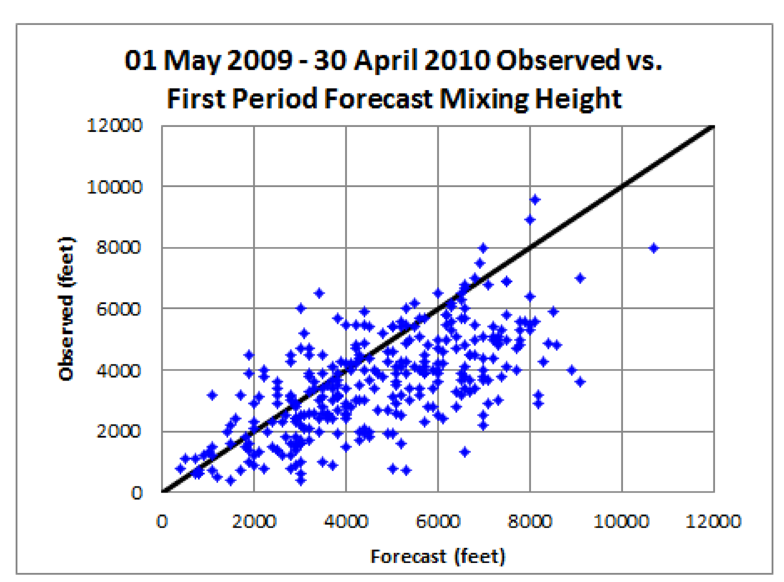


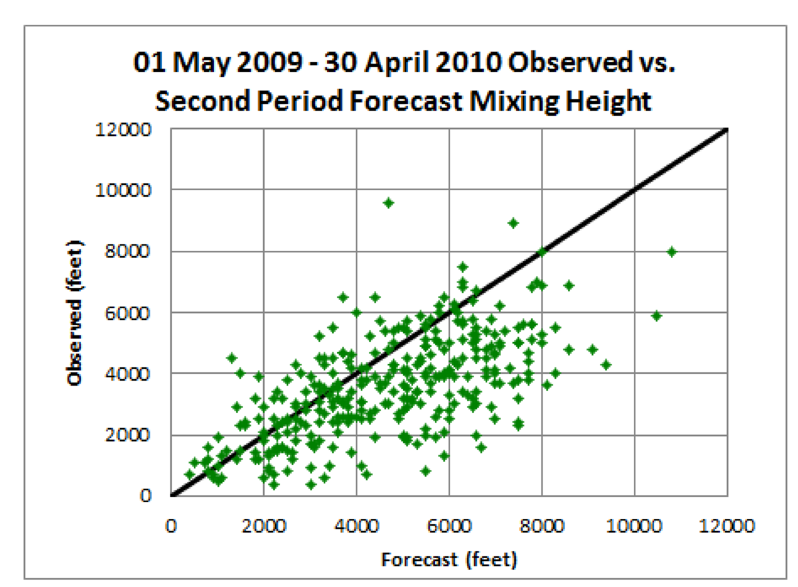


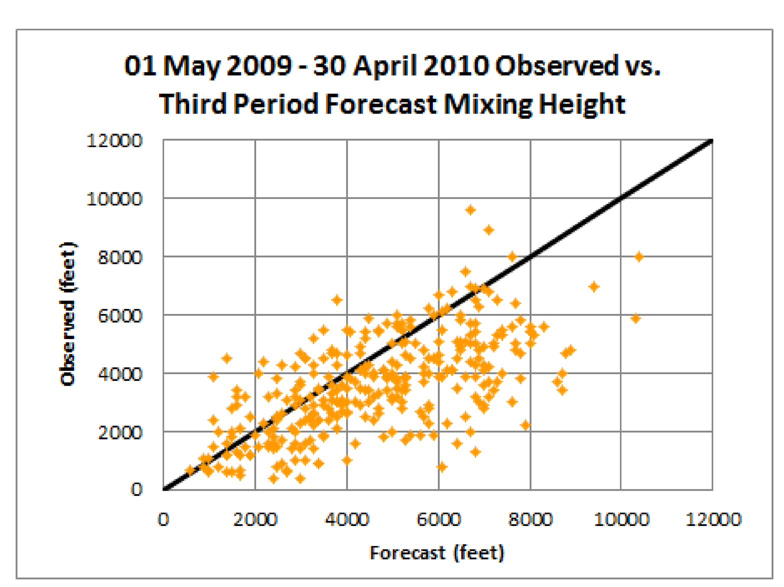


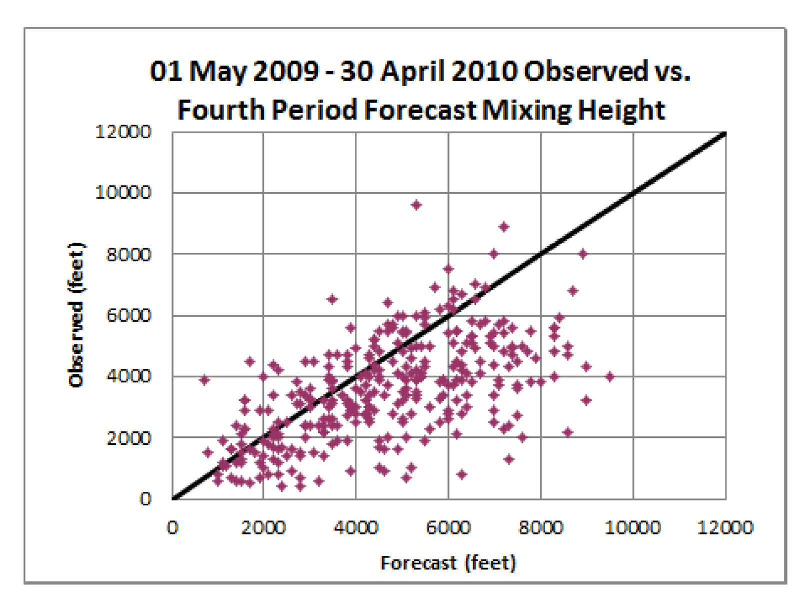


• Maximum mixing height forecasts consistently verified too high across all four forecast periods.
• A very large fraction of forecasts in excess of 6,000 feet were too high.



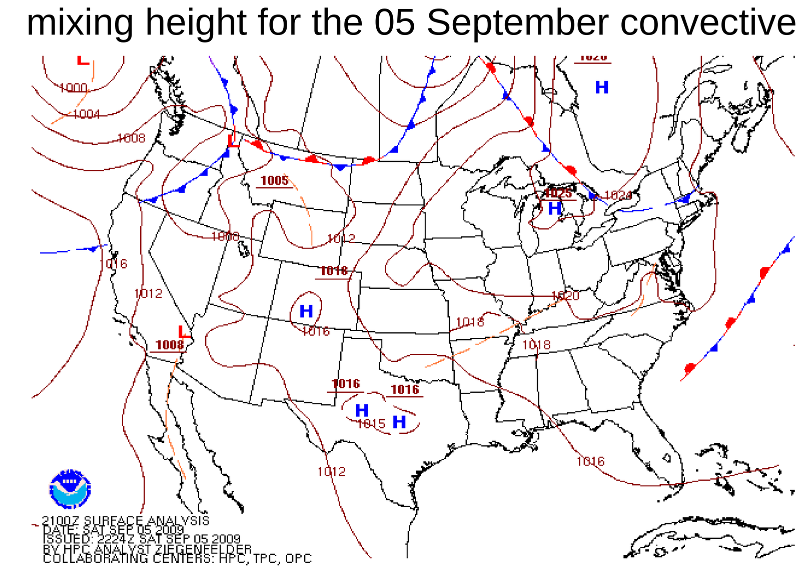


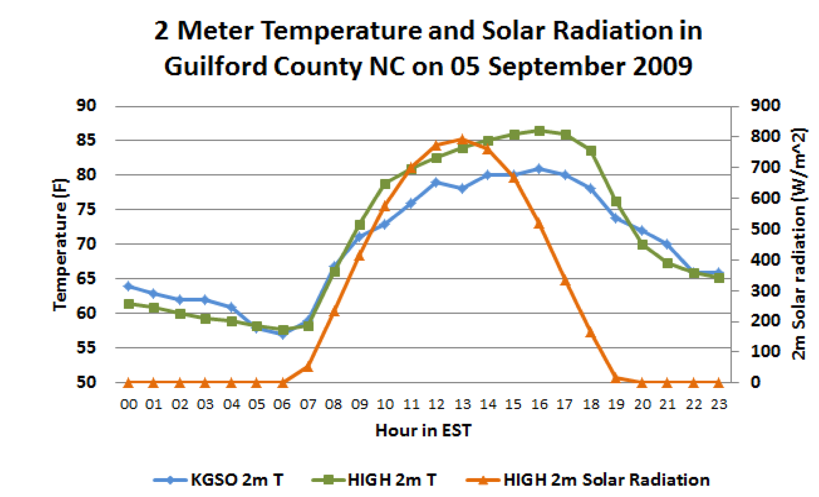


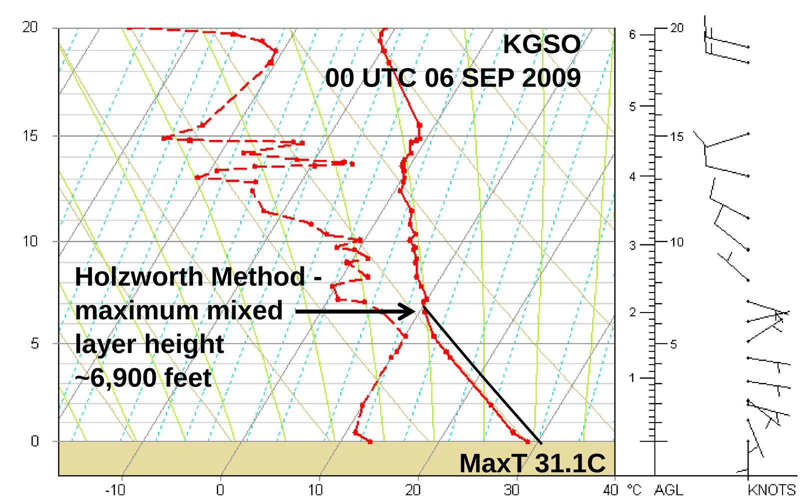


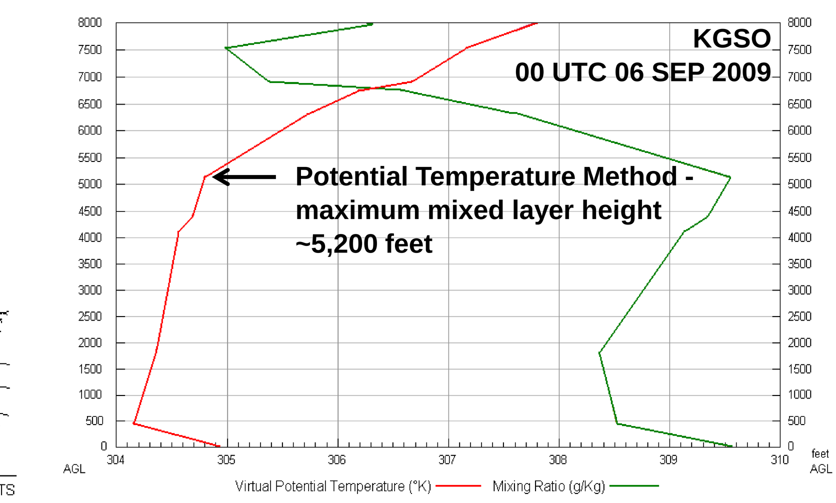
05 September 2009 Case Study

• Central North Carolina was on the western periphery of a ridge of high pressure aloft that was located off the southeast U.S. coast and under the influence of weak surface high pressure.
• Fair weather with clear skies resulted in a typical diurnal pattern of surface temperature and solar radiation across Guilford County, North Carolina.
• Given the above, a climatologically typical diurnal boundary layer evolution likely occurred. Thus it is appropriate to use the 00 UTC 06 September KGSO RAOB to determine the maximum mixing height for the 05 September convective day.









KGSO Maximum Mixing Height Forecasts and Observed for 05 September 2009

4th period forecast, issued 330 PM on 3 September	3rd period forecast, issued 526 AM on 4 September	2nd period forecast, issued 358 PM on 4 September	1st period forecast, issued 556 AM on 5 September	Average forecast from all 4 periods	Observed
6,900 feet	6,400 feet	7,800 feet	7,300 feet	7,100 feet	5,200 feet

• Forecasts from all four forecast cycles were consistently too high, with an average forecast of 7,100 feet, resulting in an average error of 1,850 feet or a mean error of 36%.
• NAM/GFS forecast BUFR soundings from the 4 corresponding forecast cycles for KGSO were examined. The average NAM mixing height forecast was 5,900 feet and the GFS was 6,550 feet, suggesting model error could be responsible for a portion of the forecast error.
• Forecasters at the NWS Raleigh typically use the Holzworth method to produce mixing height forecasts and this approach is likely the source of at least a portion of the remaining error.
• It is speculated that the subjective lifting of the surface parcel along the dry adiabat and "eyeballing" its intercept with the temperature profile may be responsible for some of the error.

Applications and Lessons Learned

• Mixing height forecasts are consistently higher than the observed mixing height, with an average first period forecast error of 1,487 feet with a mean absolute error of 58%.
• The average monthly observed mixing heights during this one year period were greatest in April and smallest in December.
• Forecasts that use the Holzworth method with a Skew-T Log-P diagram have a tendency to forecast mixing heights that are too high.
• Examining vertical profiles of potential temperature or virtual potential temperature with time along with wind speed/direction and mixing ratio is more scientifically rigorous than using the Holzworth technique alone.
• Forecasters should note that the mixing height is the height above ground level (AGL) and not mean sea level (MSL). Different sets of forecast guidance may use either AGL or MSL and with KGSO located at 926 feet above MSL, this represents another potential source of error.
• Subjective assessment suggests that model guidance may be too high with the mixing height on many days, especially during fair weather and deep mixing days.
• The degree to which any method is successful depends on the availability and resolution of data (observations or model-generated). Even when data is available, the mixing height may contain complicated structures, which makes precise definition of the top of the layer difficult.

Acknowledgements

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